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## The magneto-ionic medium in the Milky Way

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### Abstract.

One way in which the Canadian Galactic Plane Survey has made an important contribution to the understanding of the Galactic interstellar medium is through its polarization surveys. Investigation of these data has enabled a big step in the study of magnetic fields in the interstellar medium and a range of discrete, extended, interstellar objects. In this review, I will discuss the role that the magnetic field plays in the interstellar medium, summarizing the ways in which magnetic field interacts with the other components in the Milky Way. Magnetic fields in the Galactic halo are discussed, and an outlook to a number of successor surveys of the polarized CGPS in the near future is given.

## 1. Introduction

The Canadian Galactic Plane Survey (CGPS) has had broad and far reaching consequences. In particular the radio polarimetric continuum survey at 1420 MHz greatly influenced the study of magnetic fields in the Milky Way. This is largely due to the careful analysis of a variety of magnetic structures such as polarization lenses (Gray et al. 1998; Uyaniker & Landecker 2002), Galactic chimneys (West et al. 2007), supernova remnants (e.g. Uyaniker et al. 2002; Foster 2005; Kothés et al. 2006a), pulsar wind nebulae (Kothés et al. 2006b, 2008; Ransom et al. 2008), H II regions (Gray et al. 1999; Foster et al. 2006), magnetic reversals in spiral arms (Brown & Taylor 2001; Brown et al. 2003, Van Eck et al, this Volume; Rae et al, this Volume), culminating in the overview of the entire Canadian Galactic Plane in polarization (Landecker et al. 2010).

In this contribution to the meeting celebrating the CGPS, I will discuss the role that magnetic fields play in the interstellar medium (ISM) of the Milky Way. In Section 2, I will discuss energy densities of the various components in the Galactic ISM, to show the dynamic importance of the magnetic field in the Milky Way. Section 3 focuses on the various effects that the magnetic field has on the Galactic ISM, including new CGPS results concerning interstellar turbulence. A discussion of the magnetic field in the halo of the Milky Way can be found in Section 4. Finally, in Section 5 we provide an outlook to the (bright!) future of radio polarimetry for studying galactic magnetism.

## 2. Energy densities in the Galactic interstellar medium

The strength of the influence of magnetic fields on the ISM is commonly quantified by comparing energy densities or pressures of the various components. The magnetic field energy density is found to be comparable to the cosmic ray energy density, while the kinetic energy density (thermal and turbulent cold and warm gas pressures) can be in equipartition or up to twice as high as the equipartition value Boulares & Cox (e.g. 1990). Thermal energy densities are about a magnitude lower.

In nearby external galaxy NGC 6946, Beck (2004) estimated the energy densities of the magnetic field from synchrotron emission, of the thermal warm ionized gas from thermal radio emission maps, of the thermal neutral (molecular and atomic) gas from CO and HI maps, and of the turbulent component from HI line widths. He obtained the left hand plot in Figure 1, which shows energy densities of these various components of the magneto-ionic medium in the galaxy NGC 6946 as a function of galactocentric radius. Beck (2004) concluded that the magnetic field energy density is comparable to the turbulent gas density in the inner parts of NGC 6946, and dominates in the outer galaxy. Both components are more than a magnitude stronger than the thermal gas energy densities. The energy density of the rotation of the neutral HI gas is about 500 times higher than the turbulent gas density. However, the filling factor of the neutral gas is assumed to be 1 in these calculations, which may result in an overestimate of the energy density of the turbulent gas.

The right hand side of Figure 1 shows a similar plot for the Milky Way. The magnetic field energy density  $|B|^2/8\pi$  is based on equipartition values derived from radial profiles as modeled by Beuermann et al. (1985). This method was used by Elly Berkhuijsen in Beck (2001) to obtain the Galactic magnetic field strength as a function of Galactocentric radius. The figure also shows the difference between the classical equipartition formula and the revised formula based on integration over a fixed energy range instead of a frequency range (Beck & Krause 2005). The thermal gas energy density is only indicated at the solar radius and is based on standard values of the densities and temperatures of the cold, warm and hot gas components at the solar radius. The turbulent gas energy density  $\rho v_{\text{turb}}^2$  is calculated using an exponential gas scale length of 3.15 kpc and a turbulent velocity based on (McClure-Griffiths & Dickey 2007). They found that the turbulent velocity in the (inner) Galaxy is best described by three components: a cold component with a velocity dispersion  $\Delta v = 6.3 \text{ km s}^{-1}$ , a warm component with  $\Delta v = 12.3 \text{ km s}^{-1}$ , and a fast component of  $\Delta v = 25.9 \text{ km s}^{-1}$ , probably related to large-scale motions. All components are more or less constant with radius. Both the warm turbulent component with  $\Delta v = 12.3 \text{ km s}^{-1}$  and the large-scale motion component with  $\Delta v = 25.9 \text{ km s}^{-1}$  are shown in the figure. Throughout, a solar radius of 8.5 kpc is used.

Qualitatively, the situation in the Milky Way is similar to NGC 6946: the rotational energy density is more than two orders of magnitude higher than the energy densities of all other components. In addition, the magnetic and turbulent energy densities are, given the uncertainties in the assumptions made, not far off from each other, while the energy density in the thermal gas components is much less. The dominance of magnetic pressure over the thermal pressure is consistent with the observed remarkable uniformity in magnetic field strength over a wide range of gas densities (Troland & Heiles 1986). This reconfirms what we knew already: that the magnetic field in the Galaxy is a major player, in any case on large scales, which cannot be ignored.

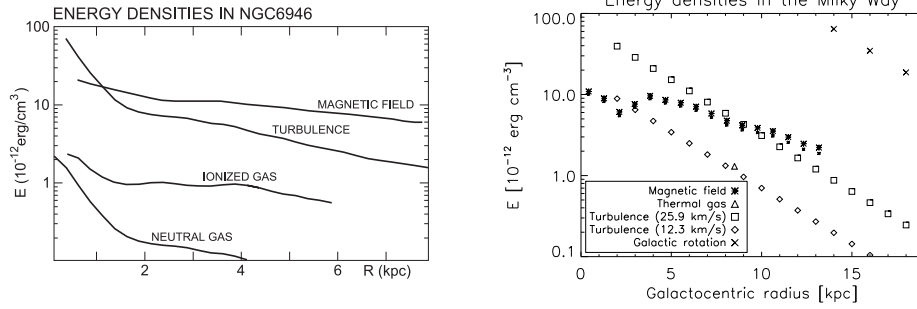


Figure 1. Left: Energy densities of various components of the interstellar medium in NGC 6946 (Beck 2004). Image courtesy of Rainer Beck, reproduced by the kind permission of Springer Publishers. Right: Galactic ISM as a function of Galactocentric radius: the magnetic field according to the equipartition function revised by Beck & Krause (2005) (large asterisks), magnetic field according to the classical equipartition formula (small asterisks), gas with a velocity dispersion of  $25.9 \text{ km s}^{-1}$  (boxes) and of  $12.3 \text{ km s}^{-1}$  (diamonds), thermal gas at the solar radius (triangle) and Galactic rotation (crosses).

### 3. The role of the magnetic field in the Milky Way

Magnetic fields interact with charged particles through the Lorentz force, which makes the particles gyrate around magnetic field lines. As most of the Universe is ionized, magnetic fields have a major influence on many of the physical processes in the Universe (mostly those where gravity is not important). Neutral particles are coupled through ion-neutral collisions. Therefore, even with fractional ionizations of  $10^{-6}$  to  $10^{-8}$  typically found in dense cloud cores (Caselli et al. 1998) the neutral interstellar medium is sufficiently ionized to expect a significant connection to magnetic fields.

There is a myriad of consequences of the interact of Galactic magnetic fields and the interstellar gas. Below I try to summarize the most important one in our Milky Way.

**Additional pressure component.** The magnetic field in the Milky Way provides a significant pressure component, comparable to the turbulent gas and cosmic ray pressures. This pressure component contributes significantly to the total pressure which counterbalances the thick gas disk ( $\leq 1 \text{ kpc}$ ) against gravity (Boulares & Cox 1990). This component also causes slower expansion of supernova remnants, see below.

**Magnetic fields and spiral arms.** Magnetic fields are also expected to influence the way in which gas flows through the spiral arms. Gómez & Cox (2002) discuss numerical magneto-hydrodynamical simulations of gas flows in a Galactic potential with a spiral perturbation. They show that simulations including magnetic fields show increased vertical velocity structure of the gas falling into the spiral arms, and a clumpier density distribution, than hydro-dynamical simulations. Large-scale magnetic field reversals along spiral arms could play a role in the gas dynamics through current sheets and/or increased magnetic reconnection, but there is still much debate about the number and location of reversals in the Galactic magnetic field (see e.g. Brown, this volume). Shukurov (2005) argues that the only unequivocally observed large-scale reversal in the

Galactic magnetic field could in fact be a 'localized' feature of a few kpc in size instead of a full-fledged magnetic field reversal along a spiral arm.

**Cosmic Ray propagation and acceleration.** Cosmic rays are coupled to interstellar magnetic fields in two ways. As cosmic rays are charged, they gyrate around magnetic field lines. The streaming motions of these particles along the field lines excite resonant Alfvén waves which then scatter the cosmic rays (e.g. Kulsrud & Pearce 1969). It is this scatter of cosmic rays off magnetic field irregularities that accelerates them to their relativistic velocities. This can happen as first-order Fermi acceleration in expanding supernova shock fronts (Blandford & Ostriker 1978), or stochastically through second-order Fermi acceleration in a turbulent gas (Fermi 1949).

Each cosmic ray electron or ion is primarily sensitive to magnetic field fluctuations on the same scale as its Larmor radius. Therefore, low-energy cosmic rays (below about  $10^{15}$  eV) are effectively scattered by the turbulent magnetic field, which makes direct tracing back to their origins impossible. It also confines the cosmic rays to the Galaxy. High-energy and ultra-high-energy cosmic rays are mostly affected by the uniform field component. Measurements of arrival directions of ultra-high energy cosmic rays by the Pierre Auger Observatory show possible clustering of detections around a number of nearby active galactic nuclei, among which Centaurus A (The Pierre Auger Collaboration 2007). As the deflection by the Galactic magnetic field is believed to be a few to a few tens of degrees, depending on magnetic field strength and direction and on cosmic ray composition, accurate measurements/modeling of the large-scale Galactic magnetic field is also vital for understanding the origins of ultra-high-energy cosmic rays.

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**Supernova remnants and superbubbles.** Surrounding large-scale magnetic fields have a direct impact on expansion of supernova remnants (SNRs). Magnetic pressure from the surrounding magnetic field slows the expansion of a SNR (Ferrière et al. 1991), while increased magnetic tension perpendicular to the magnetic field lines causes anisotropy in the expansion in the direction of the surrounding magnetic field. Also, magnetic fields limit the compression of gas in the shock (as the magnetic pressure increases as the square of compressed magnetic field), which results in smaller SNRs with thicker shells (Ferrière et al. 1991) and a smaller filling factor of the hot ionized medium than a situation without magnetic fields. However, the opposite effect is reached by significant large-scale azimuthal magnetic fields in superbubbles, which can prevent bubbles from breaking out of the disk, allowing them to grow larger.

Stil et al. (2009) performed magneto-hydrodynamical simulations of superbubble explosions in a magnetized ISM. Comparing their simulations to Galactic plane surveys, among which the CGPS, they concluded that calculated estimates of both ages of superbubbles and the scale height of the medium that they propagate in should be corrected by a factor 2 to 4 when including magnetic fields in the analysis.

Magnetic fields can have opposing effects the disk-halo interaction. A magnetic field parallel to the Galactic plane can oppose break-out of the gas (Norman & Ikeuchi 1989). On the other hand, when gas does break out and magnetic field lines open up

into the Galactic halo, it provides a funnel through which charged particles can easily escape the Galactic disk. West et al. (2007) discuss multi-wavelength observations of a fragmenting superbubble associated with the H II region W4 and find slightly enhanced magnetic fields in the shell wall of which the component parallel to the line of sight is  $\sim 3 - 5 \mu\text{G}$ .

**Interstellar turbulence.** Turbulence is a very important effect in the interstellar medium as it redistributes energy from supernova explosions back into the ISM on a wide range of scales, and it maintains the Galactic magnetic field through (small-scale) dynamo processes. In addition, magneto-hydrodynamical turbulence is a significant source of heating for the ISM (e.g. Scalo & Elmegreen 2004).

Turbulence is most readily observed and studied through observations of the 21cm neutral hydrogen line, which give direct information about the velocity field but are not suited to study the turbulent magnetic field. The turbulent component of the magnetic field in the ionized gas is investigated using polarized synchrotron emission, the Chandrasekhar-Fermi effect, but primarily Faraday rotation. Haverkorn et al. (2008) determined from Faraday rotation of extragalactic sources in the Southern Galactic Plane Survey (SGPS Haverkorn et al. 2006) that turbulent properties in the spiral arms and in interarm regions were distinctly different. Their Fig. 2, reproduced here as Fig 2, shows structure functions<sup>1</sup> of rotation measure (RM) for lines of sight primarily going through interarm regions (top row) and through spiral arms (bottom row). They concluded that RM fluctuations are present in interarm regions up to scales of about 100 pc, while in the spiral arms, no RM fluctuations on scales larger than a few parsecs exist.

Structure functions of RM in the CGPS region, for different directions of the line of sight, are shown in Fig. 3. The structure function is seen to be almost flat in the direction of the outer Galaxy, where the Perseus spiral arm is relatively nearby, while structure functions get steeper when going towards lower Galactic longitude, where the Perseus arm is located further away.

The same separation into spiral arm and interarm regions with polarized extragalactic point sources in the Canadian Galactic Plane Survey (Brown et al. 2003) is not possible because in all CGPS sight lines, spiral arms and interarm regions are superposed. However, we can assume that the conclusions drawn from the SGPS for the inner Galaxy are valid for the outer Galaxy as well and calculate the expected structure functions for a superposition of spiral arms and interarm regions. We took a very simple modeled structure function with contributions from the Perseus arm and from the interarm region in front of the Perseus arm:  $D_{\text{RM}} = D_{\text{RM,arm}} + D_{\text{RM,int}}$ .  $D_{\text{RM,arm}}$  has an outer scale of 2 pc and a maximum amplitude of  $2\sigma_{\text{RM}} = 100 \text{ rad m}^{-2}$ , and  $D_{\text{RM,int}}$  has an outer scale of 150 pc and a maximum amplitude of  $2\sigma_{\text{RM}} = 250 \text{ rad m}^{-2}$ . Since the Perseus arm is located at a different angular scale for the three plotted regions, the superposition of the two components is different. Fig. 3 clearly shows that the hypothesis of a small outer scale of fluctuations in the spiral arms, as opposed to the outer scale in the interarm regions, can also explain the observed RM structure function in the CGPS.

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<sup>1</sup>The (second order) structure function of a function  $f$  is defined as  $D_f(\delta\theta) = \langle (f(\theta) - f(\theta + \delta\theta))^2 \rangle_\theta$ , where  $\theta$  is the position of a source in angular coordinates,  $\delta\theta$  is the separation between sources, i.e. the scale of the measured fluctuation, and  $\langle \rangle_\theta$  means averaging over all positions  $\theta$ .

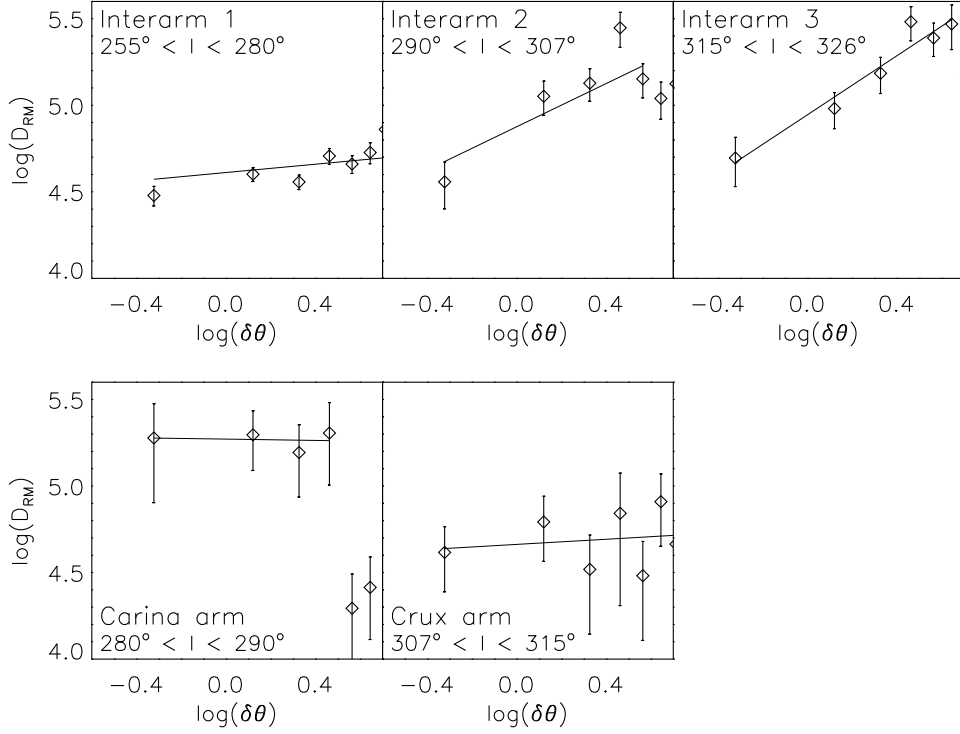


Figure 2. Structure functions of rotation measure  $D_{\text{RM}}$  as a function of angular scale  $\delta\theta$  for lines of sight in the SGPS primarily through interarm regions (top row) and lines of sight mainly crossing spiral arms (bottom row) (Haverkorn et al. 2008). Reproduced by the kind permission of the AAS.

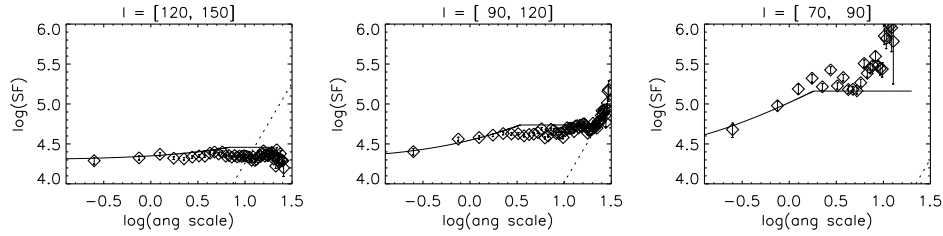


Figure 3. Structure functions of rotation measure  $D_{\text{RM}}$  as a function of angular scale  $\delta\theta$  for lines of sight in the CGPS. The overplotted lines are modeled structure functions, see the text.

**Star formation.** That magnetic fields play a role in some stages of star formation is clear, but how big that role is in which stages is still under heavy debate. The 'classical' theory of star formation describes star formation as a quasi-static process where collapse is slowed down or prevented by magnetic fields (Shu et al. 1987). This means that magnetic fields have to be strong enough to counter self-gravity, which is expressed as a mass to magnetic flux ratio below a certain value (sub-critical) (Mouschovias & Spitzer 1976).

Observations of Zeeman splitting in cold cores, however, typically measure magnetic fields large enough to suggest that most cold clouds are magnetically super-critical (e.g. Crutcher et al. 1975; Troland & Crutcher 2008). The implication is that dense cores are fairly strongly magnetized. This could happen if dense cores form out of magnetically sub-critical clouds through ambipolar diffusion<sup>2</sup> (Lizano & Shu 1989).

The alternative idea is the 'turbulent' model, where turbulence is the main mechanism controlling star formation rather than magnetic fields (e.g. Elmegreen 2000; Ostriker et al. 2001). Even though the magnetic field may not be strong enough to prevent global collapse, it can still play an important role in providing a source of pressure (e.g. Price & Bate 2007).

**Magnetic reconnection.** Magnetic reconnection occurs when magnetic field lines reorder themselves into a configuration of lower energy. This has two consequences: a change in topology of the magnetic field, and the release of magnetic energy into motion and/or heat.

Localized magnetic reconnection in the warm ionized medium at high latitudes has been invoked as a way to ionize the high-latitude gas in the Galactic halo (Birk et al. 1998). Zimmer et al. (1997) suggested that magnetic reconnection due to interaction of high-velocity clouds with the interstellar medium may be a source of heating of the interstellar gas. Fast reconnection on small scales in a magnetized turbulent medium could considerably increase the reconnection rate and allow efficient mixing of magnetic fields in the direction perpendicular to the local magnetic field direction (Lazarian & Cho 2004). Fast reconnection could avoid  $\alpha$ -quenching in the  $\alpha - \omega$  dynamo (Lazarian & Vishniac 1999), and carry away angular momentum from molecular cores in the process of star formation (Lazarian et al. 2010).

#### 4. Magnetic fields in the Milky Way halo

Magnetic fields reside not only in the Galactic gaseous disk, but also in the Galactic thick disk, or halo, magnetic field seems to be decreasing very little at least out to a few kpc. An estimated magnetic field scale height of about 4.5 kpc is a direct consequence of measured/modeled scale heights of synchrotron emission (Beuermann et al. 1985). From high-latitude pulsar rotation measures, Han & Qiao (1994) derive a magnetic field scale height of  $1.2 \pm 0.4$  kpc, a little higher than the estimate of 0.8 kpc by Simard-Normandin & Kronberg (1980). These values are reconciled if the Galactic magnetic field becomes less regular away from the Galactic plane (Boulares & Cox 1990), or if one assumes two magnetic layers with different scale heights and properties (Han & Qiao 1994), consistent with the two-layer model for synchrotron emission by Beuermann et al. (1985).

It is generally believed that galactic magnetic fields are maintained and amplified by some kind of dynamo mechanism (e.g. Ruzmaikin et al. 1988; Shukurov 2002; Widrow 2002)). The simplest model is that of the  $\alpha - \omega$  dynamo, which amplifies the radial magnetic field component through differential rotation, and amplifies the azimuthal and poloidal components of the field by turbulent loops twisted by the Coriolis

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<sup>2</sup>Ambipolar diffusion is the process in which charged particles are frozen in to the magnetic fields but neutral particles can drift under influence of gravity, slowed down by frictional drag from the ions.

force. Although the  $\alpha - \omega$  dynamo is believed to act in the Sun (Ossendrijver 2003), it is considered unable to sufficiently amplify galactic magnetic fields to observed values (eddy diffusion time scales are much shorter than time scales for amplification of the regular field, thereby suppressing turbulent motions, and quenching the dynamo). Various solutions to this problem are discussed in Widrow (2002).

For a flat disk-like galaxy which is differentially rotating, mean-field dynamo theory predicts a quadrupolar magnetic field configuration (the left side of Fig. 4), where the direction of the azimuthal magnetic field is the same above and below the plane, but the direction of the vertical magnetic field component reverses with respect to the plane. However, for a spherical, weakly rotating, structure - such as possibly a Galactic halo - the dipolar configuration is more easily excited, i.e. an azimuthal magnetic field with reversing direction across the Galactic plane, while the vertical field is directed in the same way above and below the plane (the right hand plot in Fig. 4).

These two configurations can be observationally distinguished mainly in two ways: (1) an even or odd azimuthal magnetic field direction with respect to the Galactic plane; and (2) a symmetric or antisymmetric vertical magnetic field configuration across the Galactic plane. Below, observations trying to clarify these two distinctions are briefly discussed.

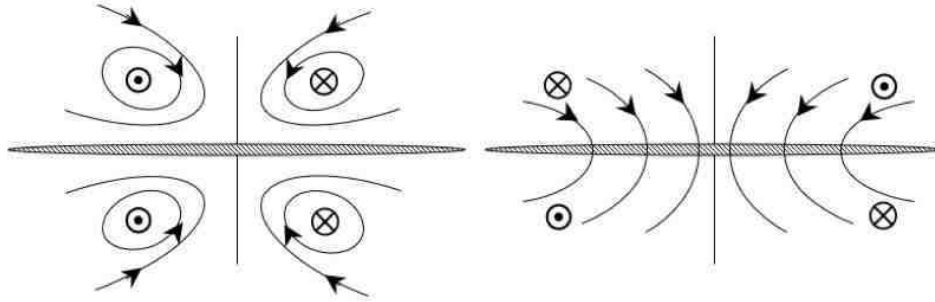


Figure 4. Possible large-scale magnetic field configurations of the Milky Way. The viewer is located outside the Galaxy in the plane, looking towards the Galactic center (the center of each graph). Magnetic field towards the viewer is denoted by a dot, field away from the observer as a cross.

**Direction of the azimuthal magnetic field component above and below the Galactic plane.** A large-scale 'butterfly pattern' in the azimuthal field component parallel to the line of sight, as shown on the right in Fig. 4, is obvious in rotation measure data (e.g. Simard-Normandin & Kronberg 1980). However, this configuration exists only towards the inner Galaxy. This has been interpreted as the signature of an A0 dynamo in the Milky Way by Han et al. (1997). However, other authors have pointed out that the quadrupolar structure in rotation measure could also be caused by nearby, large, magnetized interstellar features such as the North Polar Spur (Stil et al, in prep; Wolleben et al, in prep).

**The vertical magnetic field component in the Galactic halo.** Even though our viewpoint at the Solar radius may obscure the clarity of the configurations in Fig. 4 a bit, we can hope to detect vertical magnetic field strengths using Faraday rotation of extra-



galactic background sources to estimate a vertical component of the Galactic magnetic field. The first ones to try this were Han & Qiao (1994), who found a small vertical magnetic field of  $B = 0.3 \pm 0.2 \mu\text{G}$  from south to north. However, they worked with the a priori assumption that the field was anti-symmetric and fitted sources in north and south to one vertical magnetic field direction only. This assumption was omitted by (Mao et al. 2010), who obtained rotation measures of more than 800 polarized extragalactic sources towards both the north and the south Galactic poles at latitudes  $|b| > 70^\circ$ . They concluded that there is no vertical magnetic field component towards the north ( $B_{\text{vert}} = 0.0 \pm 0.02 \mu\text{G}$ ), and a small vertical component in the south ( $B_{\text{vert}} = 0.31 \pm 0.03 \mu\text{G}$ ). This difference could be explained by smaller scale magnetic field structure in one or both of the hemispheres, as also shown from starlight polarization (Berdyugin & Teerikorpi 2001).

Taylor et al. (2009) used rotation measure values from NVSS sources across the whole northern sky to infer vertical magnetic field components  $B_{\text{vert}} = 0.14 \pm 0.02 \mu\text{G}$  in the north and  $B_{\text{vert}} = 0.3 \pm 0.03 \mu\text{G}$  in the south. Their southern values are consistent with Mao et al. (2010). The difference in obtained  $B_{\text{vert}}$  in the north between the two studies may be attributed to the rotation measure of the North Polar Spur, which was subtracted in the Mao et al. study but not in Taylor et al.

## 5. After the CGPS

A bright future lies ahead for radio astronomy, and in particular for radio polarimetry and cosmic magnetism. A number of new telescopes, most of them path finders for the Square Kilometer Array, are coming online in the next few years, in an era of much increased recognition of the importance of magnetic fields in diffuse media. In combination with state-of-the-art technology, the method of Rotation Measure Synthesis has become feasible. RM Synthesis is based on a Fourier transform of the complex polarization as a function of wavelength squared, to obtain complex polarization as a function of Faraday depth  $\phi \propto \int_{x_1}^{x_2} n_e \mathbf{B} \cdot d\mathbf{l}$ , where  $x_1$  and  $x_2$  are locations along the line of sight. For polarized radiation from a background synchrotron source Faraday rotated by a foreground component, Faraday depth is equal to rotation measure.

The traditional method of determining RM from a small number of frequencies,  $\text{RM} = \Delta\theta/\Delta\lambda^2$ , becomes useless when synchrotron emitting and Faraday rotating plasma are mixed. In this case RM Synthesis provides a spectrum in Faraday depth, which details the mixed (Faraday-thick) medium, and any other RM and emission components along the line of sight. Although caution has to be observed when using RM Synthesis with a small number of frequency channels (Rudnick et al., in prep), the method constitutes a major step ahead in magnetic field research through radio polarimetry. For description and discussion of the method of RM Synthesis, see Burn (1966); Brentjens & de Bruyn (2005); de Bruyn & Brentjens (2005); Frick et al. (2010).

### 5.1. On-going and future radio polarimetric surveys

The largest radio polarimetric project currently underway, measured in sky and frequency coverage, is the Galactic Magneto-Ionic Medium Survey (GMIMS, PI Wolleben, Wolleben et al. 2010b). GMIMS endeavors to survey the whole sky from 300 to 1800 MHz continuously in 6 different surveys with frequency coverages of 300 to 800 MHz, 800 to 1300 MHz and 1330 to 1800 MHz, in both Northern and Southern hemispheres.

The Northern 1300-1800 MHz survey is currently being observed with the DRAO 26-m single dish (Wolleben et al. 2010a). The Southern 1300-1800 MHz survey will be filled in by the on-going associated Southern Twenty-centimeter All-sky Polarization Survey (STAPS, PI Haverkorn), and the Southern 300-800 MHz survey has also started, both with the Parkes 64-m single dish. At slightly higher frequencies than GMIMS, the S-band Polarization All-Sky Survey (S-PASS, PI Carretti) from 2.2 to 2.4 GHz has just been completed and analysis is ongoing. The Galactic Arecibo L-band Feed Array Continuum Transit Survey (GALFACTS, PI Taylor, Taylor & Salter 2010) has just started to survey the Arecibo sky (declinations  $-1^\circ$  to  $38^\circ$ ) in radio polarimetric mode from 1225 MHz to 1525 MHz, adding higher resolution to the GMIMS results.

A few more years in the future brings radio polarimetric surveys with the SKA path finders. One of the Survey Science Programs of the Australian SKA Path finder (ASKAP) under construction in Western Australia is the Polarization Sky Survey of the Universe's Magnetism (POSSUM, PIs Gaensler, Taylor, and Landecker), focusing on high-resolution surveying of the Southern polarized sky in L-band. POSSUM is proposed as a three-part survey: POSSUM-Wide, POSSUM-Deep and POSSUM-Diffuse. POSSUM-Wide is an all-sky survey which will observe 3 million polarized extragalactic point sources to obtain an "RM Grid" (Beck & Gaensler 2004). POSSUM-Deep is a deep observation of 30 square degrees on the sky to determine the polarization properties of faint sources. Diffuse POSSUM intends to survey the whole sky with the maximum frequency coverage of 700 to 1800 MHz to image diffuse polarization with RM Synthesis. Depending on the outcome of the time allocation process, the POSSUM surveys will be observed commensally with other ASKAP surveys with similar observing constraints.

At low frequencies, the LOw Frequency ARray (LOFAR) is able to detect low rotation measures and therefore weak magnetic fields, and is therefore ideally suited to investigate magnetic fields in the Galactic halo. A Galactic Science subgroup within the Cosmic Magnetism Key Science Project has proposed broadband radio polarimetric observations of many fields away from the galactic plane.

LOFAR consists of two kinds of antennas, the Low Band Antennas (LBAs) with a frequency coverage of 10 - 90 MHz, and the High Band Antennas (HBAs) from 110 - 240 MHz. These antennas are grouped in stations, which are located in the Netherlands and throughout Europe. At this time, international stations are being built in Germany, France, Sweden, and the UK, although more international stations are in various stages of planning. Each station consists of 96 LBA antennas, and 48 (Dutch) or 96 (international) HBA antennas. A cabinet at each station collects the signals from all antennas and performs some processing such as station calibration or station beam forming. High-speed glass-fiber connections connect all stations to the Blue Gene P supercomputer at the Computing Centre of the University of Groningen, where signals are processed through one of the available data reduction pipelines. At the moment, pipelines for imaging, transient detection, pulsars, high-energy cosmic ray air showers, and rotation measure synthesis are in various stages of development and testing.

## 6. Conclusions

The polarized Canadian Galactic Plane Survey has played a large role to convince a growing part of the astronomical community of the importance of Galactic magnetic fields in many physical processes. The interactions of magnetic fields with the gaseous

and cosmic ray components in the Milky Way, as described above, can only be understood if sufficient high-quality observations of magnetic field strengths and directions and their influence on the surrounding ISM are available. Here, the CGPS is in particular valuable because of its multi-wavelength character, allowing both magnetic fields and ISM components to be studied simultaneously, and because the CGPS team excels in thorough and careful analysis of the observations to reach solid observational conclusions. Partially due to the CGPS polarization efforts, galactic magnetism has become a thriving field of research. Now, cosmic magnetism is one of five key science areas for the Square Kilometre Array, assuring many exciting developments in the years to come.

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